Magnetic memory of dislocations in NaCl single crystals

Yu. I. Golovin and R. B. Morgunov
Tambov State Pedagogical Institute, Tambov, Russia

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Long-lived ($\sim 10^3$ s) excited states of edge dislocations have been observed to form in diamagnetic NaCl crystals when a static magnetic field $B = 1$ T is applied.

In a series of recent papers, Al'shits *et al.*[1-3] have described a significant increase in the mobility of dislocations in diamagnetic crystals (NaCl, Al, Zn) when they are subjected to a relatively weak static magnetic field $B \simeq 1$ T. In principle, the magnetic field might affect the structure and state of the dislocations themselves, those of local stops (which determine the mobility of dislocations in these crystals), and the interaction between them when they are within distances on the order of interatomic distances from each other. The particular experiments carried out in Ref. 1–3 were of such a nature that the investigators were unable to distinguish among these three possibilities. In the absence of definitive information, these investigators were inclined toward the last of these explanations. One specific mechanism of this sort is described in Ref. 4. On the other hand, it is known that the magnetic susceptibility of a diamagnetic or paramagnetic crystal is sensitive to the number of dislocations in it.[5,6] Corresponding experimental and theoretical results reported in Refs. 7 and 8 indicate that there is the possibility in principle of a 1D magnetic ordering of a ferromagnetic type in a dislocation core. Admittedly, subsequent attempts to experimentally study the residual order at dislocations in ionic crystals or even to reproduce the results of Ref. 6 have been unsuccessful, to the best of our knowledge. One could probably propose other mechanisms by which a magnetic field might affect the properties of dislocation, e.g., through a change in atomic structure and in the configuration of the dislocation cores.

In this letter we are reporting an effort to observe the effect of a magnetic field $B = 1$ T on the properties of dislocations themselves in diamagnetic NaCl single crystals (the concentration of impurities with a different valence was $\sim 10^{-4}$ mole %). As an indicator and a measure of this effect, we selected the velocity at which dislocations move in the field of a calibrated square pulse of compressional stress (with an amplitude of 0.1 MPa, a length of 6 s, and a rise time of 10 ms). This compression pulse was applied to a sample ($\sim 4 \times 5 \times 12$ mm) after a magnetic field was applied for a time t_1 and then turned off, at a time t_2 before the application of the mechanical load (Fig. 1). It turns out that the mobility characteristics of edge dislocations are far more sensitive than the magnetic susceptibility to magnetic fields.

Since there was no magnetic field during the loading of the crystal, the third type of mechanism for an effect of the field on the dislocation mobility (the third of the mechanisms listed above) was ruled out by the design of the experiment. To distinguish the contributions from the first two mechanisms, we carried out two series of

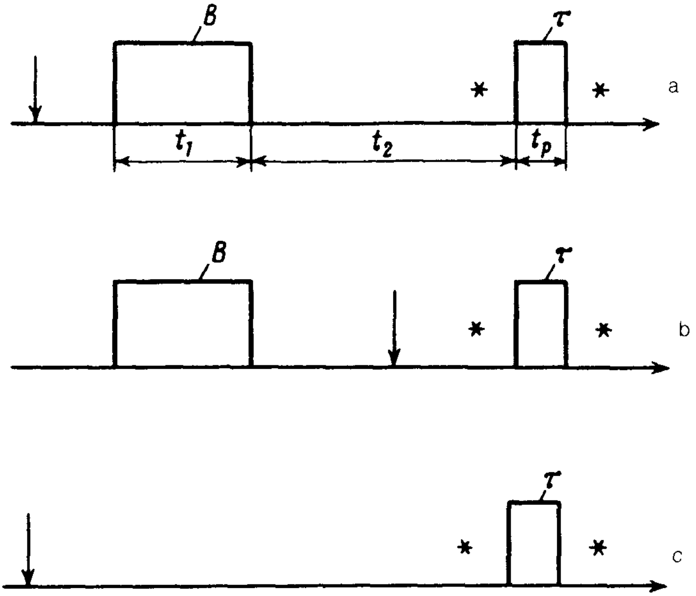

FIG. 1. Sequences of procedures in the experiments of the various types. Arrows—Times at which dislocations are introduced; asterisks—etching times; t_1—length of magnetic-field pulse; t_2—length of pause between the pulses of the magnetic field and the mechanical loading; $t_p = 6$ s—length of the mechanical-loading pulse.

experiments, differing only in the sequence of procedures (Fig. 1). In the first series, some fresh dislocations were introduced. The sample was then placed in an electromagnet and held in the field for a time ranging from a few seconds to several hours. The positions of the dislocations were determined by a first etching. After the field was turned off, and after a pause of duration t_2 (which also ranged from a few seconds to 2 h), the crystal was mechanically loaded, and the sample was etched again.[1)] The average dislocation velocity v was found by averaging 3×10^2–10^3 displacements of individual dislocations in each sample and dividing the average displacement by the duration of the load pulse.

The experiments of the second series differed from those of the first only in that the dislocations were added to the crystal after, rather than before, the imposition of the magnetic field (Fig. 1). In both series, we observed that v was larger than in control experiments without a magnetic field (Fig. 2). Consequently, structural elements of some sort "remember" the fact that time was spent in a magnetic field. The increase in the velocity v of the dislocations introduced after the imposition of the magnetic field is evidence that these structural elements may be local stops. An even greater increase in mobility was observed for dislocations introduced before the imposition of the magnetic field.

The difference between the dislocation velocities in the first and second series of

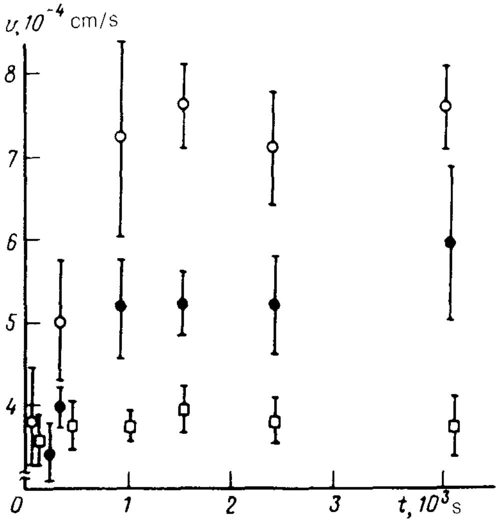

FIG. 2. Average dislocation velocity versus the time spent in the magnetic field. ●—In experiments of type *a* in Fig. 1; ○—type *b*; □—control experiments without a magnetic field.

experiments, $\Delta v = v_1 - v_2$, characterizes the residual changes in the structure and other properties of the dislocations which had been exposed to a magnetic field. This difference indicates that the dislocations also "remember" the application of the magnetic field. As the time the sample spent in the magnetic field is raised, the difference Δv increases (Fig. 2). It reaches saturation at $t_1 > 2 \times 10^3$ s. The aftereffect of the magnetic field is only temporary; it decays with increasing length of the pause between the time the field is turned off and the time the mechanical load is applied (Fig. 3), with a time

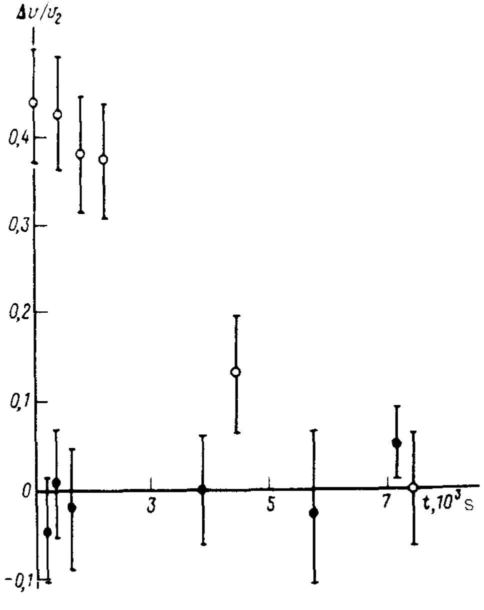

FIG. 3. ○—Kinetics of the relaxation of the magnetic "memory" of a dislocation versus the duration of the pause between the pulses of the magnetic field and the mechanical loading; ●—control experiments without a magnetic field.

constant $\sim 3 \times 10^3$ s. Control experiments showed that this relaxation was unrelated to an aging or pinning of dislocations, since in samples which were not exposed to a magnetic field a pause of up to several hours between the introduction of the dislocations and the application of the mechanical load did not result in any significant decrease in the mobility of the dislocations. The displacements of the dislocations at various faces of a given crystal were statistically indistinguishable. The same was true for the displacements of dislocations in different directions, i.e., with different angles between the vector **B** and the Burgers vector **b** (45°, 90°, 135°, −45°, −90°, −135°), and also between **B** and the dislocation line (0°, 90°) This "memory" of the fact that the sample has spent time in a magnetic field is also seen in quenched and γ-irradiated samples (the irradiation dose was 10^6 rad).

Analysis of the distribution of dislocations with respect to displacement by the technique proposed by Argon[9] shows that the increase in v after the imposition of the magnetic field occurs because of an increase in the average magnitude of the jumps of the dislocations. In addition, for certain orientations of the magnetic field we observed an increase in the time the dislocations spent at stops. There are thus at least two types of stops in the crystal, and the magnetic field has different effects on the sensitivity of dislocations to the two types: The field reduces the sensitivity to stops of one type, while simultaneously increasing the sensitivity to stops of the other type.

The microscopic mechanism for this magnetic memory of dislocations requires further research. Nevertheless, the long times which are required for the appearance and relaxation of this effect ($\sim 10^3$ s) and the relative insensitivity to the presence of F centers and the state of the impurity may indicate that the magnetic field can act on not only the electronic structure but also the atomic structure of dislocation cores. For example, it may do this by changing the configuration of the dislocation line, the concentration and height of steps and kinks on it.

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[1)] In contrast with the results of Refs. 1 and 3, the magnetic field alone—without an external mechanical load—did not cause a displacement of the dislocations in our crystals.

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